

LEFT ATRIAL, "PULMONARY CAPILLARY", AND ŒSOPHAGEAL BALLOON PRESSURE TRACINGS IN MITRAL VALVE DISEASE

BY

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In selecting patients for mitral valvotomy, the exclusion of mitral insufficiency by common clinical methods has proven unreliable. We endeavoured to determine whether preoperative "pulmonary capillary" pressures and tracings taken by means of a balloon in the œsophagus at the left atrial level would be of value in the diagnosis of mitral insufficiency. Pressure pulses were also obtained directly from the left atrium at operation; their characteristics in mitral stenosis and mitral insufficiency were studied, and they were correlated with the "P.C." and œsophageal balloon tracings, since the latter two are of value only in so far as they reflect hæmodynamic events within the left atrium. To accomplish these aims, we set out to obtain all three types of tracing in each of a series of 30 patients who were operated upon for the relief of mitral stenosis.

We relied upon the surgeon's finger to detect insufficiency. Both the size of the mitral orifice and the presence of a régurgitant jet were taken into consideration (Wynn *et al.*, 1952). These criteria may be inadequate but must serve until better ones are devised.

HISTORICAL REVIEW

Left atrial pressure pulses in the patient with mitral stenosis were first recorded by Munnell and Lam (1951). Wynn *et al.* (1952) reproduced and analyzed a large number of left atrial curves taken at operation in patients with normal hearts and with mitral valve lesions, and concluded that the normal left atrial pressure pulse resembled that in the right atrium except that the amplitude of the late systolic wave (which will be called the "V" wave) was greater on the left side. Patients with pure mitral stenosis and sinus rhythm showed left atrial tracings resembling the normal, although the level of pressure was higher. When auricular fibrillation was present, the pressure rose sharply at the onset of ventricular contraction and there was little or no drop in early systole such as occurred in sinus rhythm (the "descent of the base" of the heart). That this early systolic pressure rise did not necessarily indicate mitral insufficiency was attested to by the fact that the rise was greatest when the preceding diastole was shortest. That is, it was inversely proportional to the completeness of ventricular filling and therefore perhaps dependent upon the distention of the auricle. In the presence of mitral stenosis, mitral insufficiency did not produce any constant qualitative change in the form of the left atrial pressure tracing. However, one patient with mitral insufficiency and sinus rhythm showed a pressure rise in late systole of 25 mm. Hg, higher than in any case of pure mitral stenosis.

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In a group of left atrial pressure pulses taken by the transbronchial route, Facquet *et al.* (1954) confirmed most of Wynn's findings but attributed more importance to a high V wave as an indication of mitral insufficiency. When rapid auricular fibrillation was present, however, a high V wave had no such significance, according to Facquet. A high V wave was also found in a patient with left ventricular failure without mitral valve disease. Unfortunately, there was no surgical or post-mortem confirmation of the diagnosis of mitral insufficiency in this group of patients.

Left atrial, and in most cases left ventricular, pressure pulses, were recorded by Venner and Holling (1953) in a series of patients with mitral valve disease coming to operation. These authors concluded that mitral insufficiency did not lead to characteristic changes in the left atrial tracings, presumably because the volume of regurgitant blood was small in comparison with the volume of the left atrium and the pulmonary veins.

"*Pulmonary capillary*" Pressures. The concept that a pulse wave reflected from the left atrium may be recorded from the distal end of a severed branch of the pulmonary artery apparently originated with MacCallum and McClure (1906). These authors produced mitral insufficiency in animals and demonstrated a regurgitant pressure wave in the left atrium and in the transected pulmonary artery "receiving pressure from the lung only." Hellems *et al.* (1948, 1949) by wedging a cardiac catheter into a distal branch of the pulmonary artery, obtained what they termed "pulmonary capillary" pressures in animals and man. Lagerlöf and Werkö (1949) confirmed and further characterized such pressures, while Dow and Gorlin (1950) demonstrated that mean pressures in the "P.C." tracings were reliable indices of left atrial mean pressure in dogs. Gorlin *et al.* (1951) and Lagerlöf and Werkö were the first to suggest that it might be possible to diagnose mitral insufficiency from the "P.C." tracing (i.e. by the finding of a high late systolic wave).

There have been subsequent reports by van Bogaert *et al.* (1952), Werkö *et al.* (1953), Allison and Linden (1953), and Björk (1954) for and against the concept that the two pressures mirrored each other both in form and in absolute value in patients with mitral valve lesions. Simultaneous or immediately consecutive pressure tracings by Connolly *et al.* (1953) and by Epps and Adler (1953), using the bronchoscopic method, left little doubt, however, that in patients with mitral valvular lesions the "P.C." pressures correlated closely with the direct left atrial pressure. Connolly *et al.* were unable to distinguish mitral stenosis from mitral insufficiency on the basis of "wedge pressures." They found that most patients with mitral insufficiency showed high V waves, but many cases of pure mitral stenosis also had them, and one patient with mitral insufficiency did not. They found a fairly constant delay amounting to 0.05 sec. of the "P.C." compared to left atrial tracings. Epps and Adler added the observation that C waves were present but small in left atrial pressure curves but that these were less evident in "P.C." tracings.

A comparison of "P.C." with direct left atrial curves led Wolter *et al.* (1953) to conclude that there was good correspondence between the two. They stated that it might be possible to recognize even mild degrees of mitral insufficiency from the "P.C." curve and that one of the important criteria was the failure of the pressure to drop to the base line during systole. They recognized, however, that when auricular fibrillation was present this finding was of no significance.

When mitral stenosis was combined with mitral insufficiency, Soulié *et al.* (1954) found that the "P.C." pressure pulse was suggestive of mitral insufficiency only when the jet found at operation was of considerable size. In most cases the V wave was high and sharp, particularly when sinus rhythm was present.

Esophageal Balloon Tracings. Left atrial pulsations have been recorded by means of a balloon in the esophagus for many years (Minkowski, 1907; Rautenberg, 1907). Lasser and co-workers (1952) revived the method, using a fluid-filled system and modern equipment, and demonstrated the resemblance between what they termed the "esophageal piezocardiogram" and direct left atrial pressures in animals under varying conditions, and with experimentally produced valvular lesions: they described such tracings in subjects with normal hearts and with mitral valve disease. Mitral stenosis was characterized by a sharp, early systolic peak, whereas mitral insufficiency

showed a later systolic pressure rise. With combined lesions they found an early systolic pressure peak followed by a secondary rise later in systole. No direct left atrial pressures were available in these cases, however.

Van den Heuvel-Heymans (1952), using Lasser's technique, compared the œsophageal balloon tracings with direct left atrial pressure pulses taken at operation in the same patients, confirming the basic similarities between the two. Characteristic alterations of both œsophageal balloon and direct left atrial pulses were observed in mitral valve disease. Thus, he reported that a single-peaked high V wave, higher than the C wave, was characteristic of pure mitral insufficiency. He also attributed diagnostic significance to the pressure drop after the C wave, stating that it was smaller in combined stenosis and insufficiency than in pure stenosis. This paper contains one illustration showing the resemblance between "P.C.," œsophageal balloon and direct left atrial pressure pulses in a single case.

Abelmann *et al.* (1953) found a positive systolic wave which they considered characteristic for mitral insufficiency, although the same pattern was also found in some cases of mitral stenosis in whom no regurgitant jet was found at operation. This, they claimed, tended to confirm the contention that most patients with mitral stenosis have some mitral regurgitation.

A large number of patients with and without heart disease were studied by Zoob (1954) but he used a more compressible system which was apparently filled with air rather than liquid. His tracings are therefore not strictly comparable with those mentioned or with ours, which were all obtained with liquid-filled systems. Zoob attached diagnostic importance to the fact that in pure mitral incompetence the apex of the V wave preceded the second heart sound, but concluded that the diagnosis of incompetence in the presence of mitral stenosis was difficult.

MATERIAL

Thirty patients were studied. They ranged in age from 28 to 50 years. There were 22 women and 8 men. On the basis of complete clinical, electrocardiographic, and radiologic studies, 27 of these patients were thought to have pure mitral stenosis. Of the remaining three, in whom the presence of mitral insufficiency was also suspected, two proved to have this lesion at the time of thoracotomy, and valvotomy was not performed. Mitral insufficiency of significant degree was also found in three patients in whom it was not suspected. Three patients with absent or minimal mitral incompetence before valvotomy, developed marked regurgitation afterwards.

It need scarcely be emphasized that this group of cases was carefully selected before operation to eliminate those with mitral insufficiency. To the degree that we were successful in this, our study suffers from a paucity of patients with this lesion.

Cardiac catheterization was performed in 27 of these 30 patients. Œsophageal balloon tracings were obtained in all. Direct left atrial pressure pulses were obtained during surgery in all before valvotomy, and in most afterwards. In some cases left atrial, left ventricular, and aortic pressure pulses were obtained simultaneously on the same ordinate scale and with manometers of the same sensitivity (Gordon *et al.*, 1954). "P.C." and œsophageal balloon tracings were taken several days before operation.

METHODS

Statham (P23 A) pressure transducers were used throughout. In the first 15 cases a four-channel direct-writing instrument was used in which a heated stylus recorded on heat-sensitive paper. The paper speed of this instrument was 25 mm. per second. In the latter half of the studies we used a four-channel cathode-ray photographic recording system* for three pressure channels and simultaneous electrocardiogram. Paper speed was either 25 or 50 mm. per second. We used the latter almost exclusively. The reference electrocardiogram was almost always lead II.

Left atrial pressures were taken by means of a 20 gauge, short bevel needle 3.7 cm. long, thrust

* Made by Electronics for Medicine, Inc., New York, N.Y.

through the atrial appendage. The needle was connected to the pressure transducer by a length of lead or thick plastic tubing, fitted with Luer adapters. The lead was 8 mm. in outside diameter and 3 mm. inside diameter. The vinyl plastic measured 7 mm. in outside diameter, with a bore of 1.75 mm.* The zero point for the manometers was at the mid-atrial level as determined in the open chest.

Pulmonary capillary pressures were obtained during cardiac catheterization by the standard technique of Hellems *et al.* (1949). With rare exceptions, 8F catheters were used, 125 cm. long and with bird's-eye tips. The zero point for pressures was 5 cm. below the angle of Louis with the patient supine. In most cases these pressures were recorded during quiet respiration. Criteria for "P.C." pressures were: (1) the contour of the tracing, which was distinctly different from that of the pulmonary artery in the same patient; (2) the characteristic snapping back of the catheter when its tip was gradually withdrawn, indicating that it had been tightly wedged; (3) in many cases when attempts were made to aspirate blood either no blood could be obtained, or that which was obtained was fully saturated with oxygen.

The *oesophageal balloon* was made from a cylinder of latex cut from the finger of a surgical glove, fixed on to a length of polyethylene tubing† about 10 cm. from its tip. This tubing had an outside diameter of 4 mm. and inside diameter of 3 mm. The entire system was filled with a mixture of water and sufficient 35 per cent Diodrast to permit fluoroscopic visualization of the balloon. Bubbles were eliminated from the system as much as possible, although a tiny one usually remained. When inflated, the balloon measured 3.1 cm. long and was of the same diameter. The distance from the proximal end of the balloon to the stopcock on the end of the polyethylene tube varied in different balloons from 1.2 to 1.5 metres. The longer tubes were more convenient to work with, although possibly introducing a slight error in timing. In order faithfully to record left atrial events the balloon must be relatively small, otherwise the tracings will be distorted by pressure or volume changes taking place at other than the desired left atrial level.

The patient's oropharynx was anaesthetized with a 2 per cent pontocaine spray and the balloon was passed into the oesophagus in a deflated condition. It was then inflated with 5–15 c.c. of the water-diodrast mixture, and could then be placed at the left atrial level under fluoroscopic control. Tracings were made at various levels, and with different degrees of inflation, with the patient erect. It was usually necessary to suspend respiration while the records were being made. No attempt was made to measure absolute pressures from these tracings, as the amplitude of the pressure pulse is a function of the elasticity of the system, the amount of fluid in the balloon and the initial pressure within it, as well as the intra-atrial pressure.

LEFT ATRIAL PRESSURES

Of the three types of pressure pulse under study, direct left atrial pressures were the easiest to obtain, measure, and interpret, and showed the fewest artefacts. Only when thrombus material was present in the left atrium were we unable to obtain satisfactory curves. Respiratory variations were rarely observed, presumably because of the open chest. Our findings agree very closely with those of Wynn *et al.* (1952).

Normal Left Atrial Pressures. We were able to study only a few left atrial pressures in normal hearts. These were obtained simultaneously with left ventricular and aortic curves, and recorded with manometers of the same sensitivity with identical base-lines, as part of another study. Mean pressures in these left atrial control pressures averaged less than 10 mm. Hg. A, C, and V waves could be identified, the first usually higher than the second, and the V wave usually the highest of all, occasionally reaching a peak level of 12 mm. Hg. Because of the lower general level of pressures, artefacts, presumably due to motion of the plastic tubing, were occasionally more troublesome than in the cases with mitral valve disease.

* Made by U.S. Catheter and Inst. Co., Glens Falls, N.Y.

† P.E. 350, Clay Adams Co., N.Y.

Mitral Stenosis, Sinus Rhythm. Eleven patients fell into this category (Fig. 1, 2, and 3). The pressure pulses showed considerable variation, but in general were similar to the normal, except that the pressure level was considerably higher. Thus, the mean pressures averaged 27 mm. Hg, the highest measuring 43 mm. and the lowest 8 mm. The highest point of pressure recorded in any of our cases occurred in a patient in this group, the peak of whose V wave measured 60 mm. The left atrial pulse pressures averaged 16 mm.

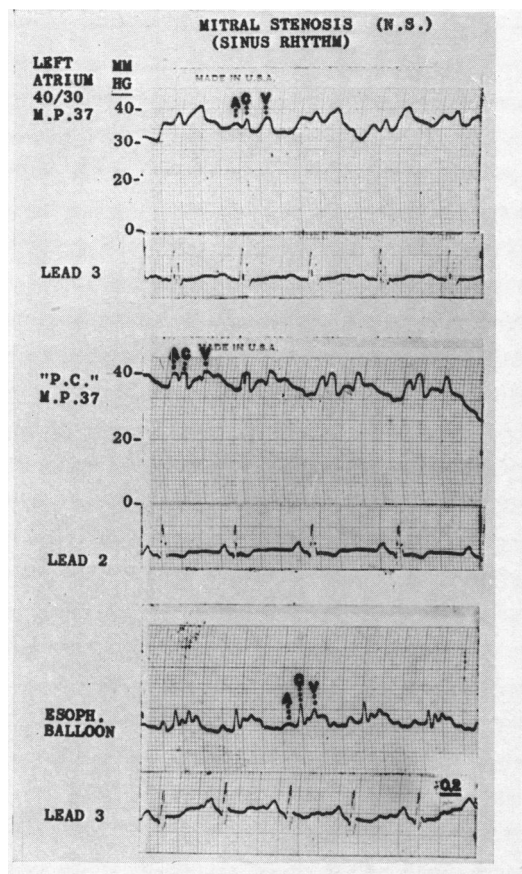


FIG. 1.—A patient with mitral stenosis and sinus rhythm, in whom all three tracings were similar. Note the irregularity of the V wave in the "P.C." and balloon tracings. (Paper speed = 25 mm. per second.)

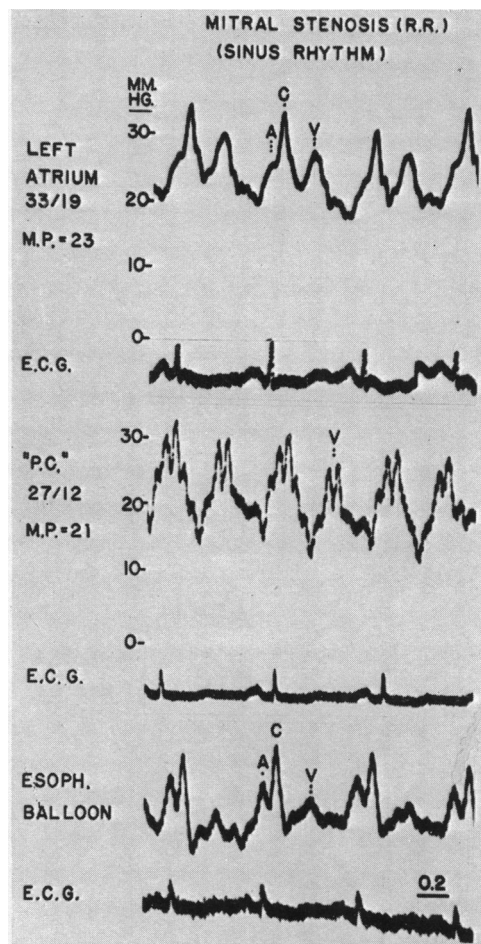


FIG. 2.—Note the strong resemblance between the left atrial and oesophageal balloon pressure pulses. (Paper speed = 50 mm. per second. E.C.G. = lead II unless otherwise indicated.)

None of the three waves was consistently higher than the others in this group. The C wave often occurred on the upstroke or down stroke of the A wave, so that the point of onset of these waves often could not be determined for purposes of timing. Sometimes, particularly when artefacts were present, the C wave could not be identified. The V wave was usually a single large wave but occasionally was split. In several cases it was much higher than the A and C waves.

Mitral Stenosis, Auricular Fibrillation. Eleven cases fell into this category (Fig. 4). The mean pressures averaged 24 mm. Hg with a range from 11 mm. to 35 mm. Hg. The highest point of

pressure in this group was a V wave 45 mm. high. The left atrial pulse pressures averaged 12 mm. Hg. As described by Wynn, the A wave was absent, the pressure rose abruptly with the C wave and dropped only slightly thereafter, giving a plateau-like appearance, in which the C wave formed the first hump and the V wave the last. The C and V waves were usually about the same height but occasionally the V wave was much higher. The height of the plateau pressures varied inversely with the length of the preceding diastole, i.e. it tended to be lower with more complete left atrial emptying. Arrhythmias other than auricular fibrillation gave rise to a similar picture depending on the time of atrial contraction. For instance, in nodal rhythm, the C and A waves were usually summated.

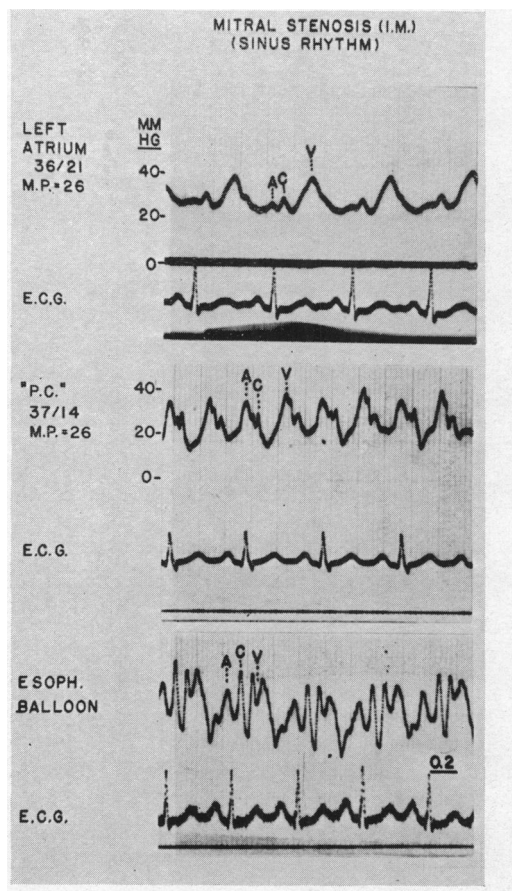


FIG. 3.—The left atrial pressure pulse in this patient with pure mitral stenosis shows a tall V wave. (Paper speed = 50 mm. per second.)

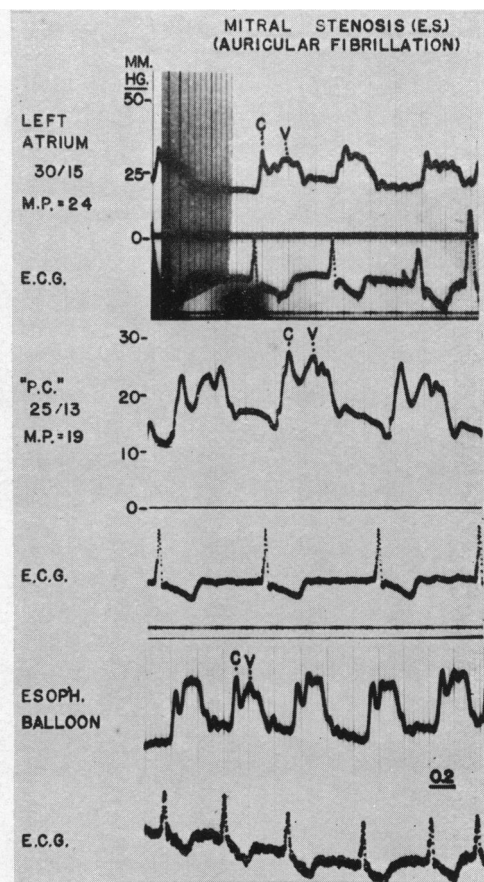


FIG. 4.—In this case of mitral stenosis with auricular fibrillation all three tracings show striking resemblances. (Paper speed = 50 mm. per second.)

Mitral Stenosis and Insufficiency, Sinus Rhythm. Only two of our patients had combined mitral stenosis and insufficiency, with sinus rhythm. In one case, in which the jet was described as minimal, the pressures were 35 mm. Hg maximum and 17 minimum, with a mean pressure of 26 mm. This curve did not differ in any way from that found in pure mitral stenosis. In the second case with moderate mitral insufficiency the left atrial pressures amounted to 40/25 mm. Hg, mean pressure 32 mm. and pulse pressure 15 mm. Although the V wave was prominent in this patient, the curve dropped to the base line after the C wave (Fig. 5).

Mitral Stenosis and Insufficiency, Auricular Fibrillation. Four patients with auricular fibrillation showed minimal to moderate regurgitant jets at operation as appreciated by the surgeon's finger. In one of these, although a satisfactory curve was obtained, only the pulse pressure could be measured, for technical reasons. In one other, only the mean pressure was obtained. The average of the three mean pressures was 29 mm. Hg. The average of the pulse pressures in the three cases where it could be measured, was 9 mm. Hg. In three of the four patients, the curves could not be distinguished from those of pure mitral stenosis; in the fourth the V wave was higher than that usually found in mitral stenosis alone.

Mitral Insufficiency without Stenosis. In the one patient with sinus rhythms (Fig. 6), valvulotomy was not performed. The left atrial pressure was 30/17, with a mean pressure of 23 mm. Hg and pulse pressure of 13 mm. Hg. The curve did not differ from the others in any important respect. The one patient with auricular fibrillation (Fig. 7) had a left atrial pressure

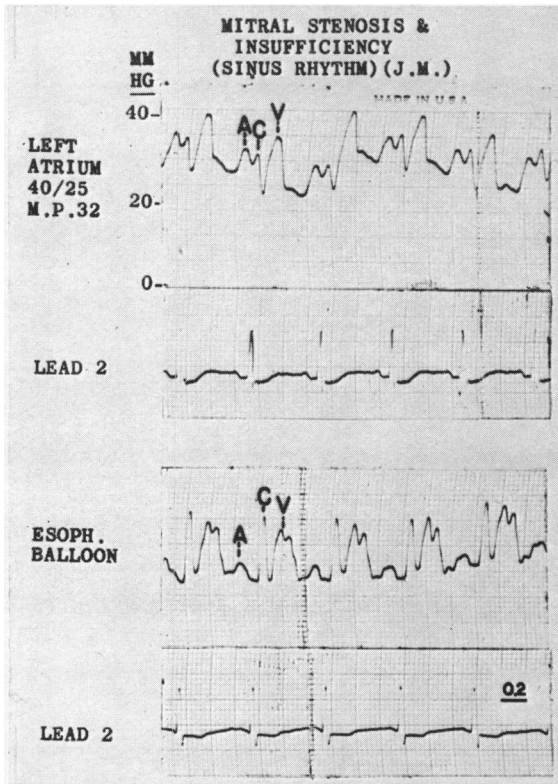


FIG. 5.—See text for description. (Paper speed = 25 mm. per second.)

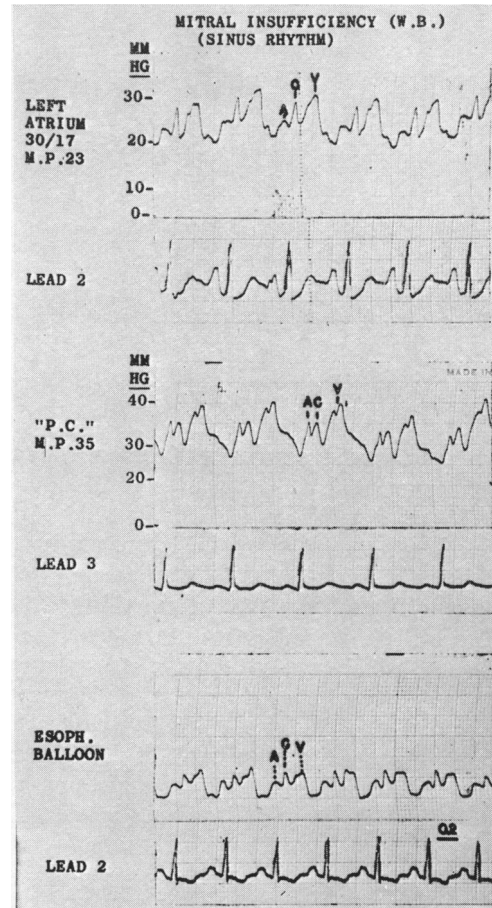


FIG. 6.—See text. (Paper speed = 25 mm. per second.)

of 55/35 with a mean of 40 mm. Hg and pulse pressure of 20 mm. Hg. The tracing was of the plateau type but with a gradual rise in pressure from the C to the peak of the V wave. The late systolic rise in pressure would suggest mitral insufficiency according to previously proposed criteria.

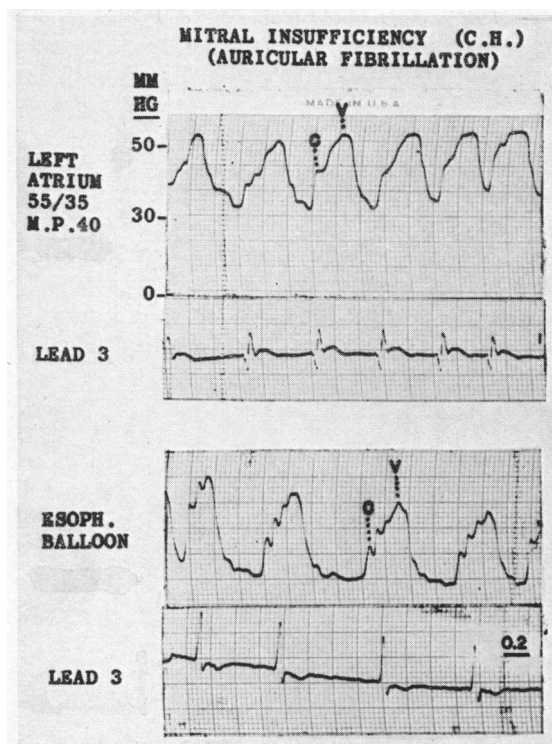


FIG. 7.—See text. (Paper speed = 25 mm. per second.)

However, we have mentioned before that this type of tracing may occur in pure mitral stenosis when associated with auricular fibrillation.

Mitral Insufficiency developing after Valvotomy. Three patients developed strong regurgitant jets after the valve was widened where previously insufficiency had been slight or absent. In one of these the left atrial tracing taken after valvotomy was exactly the same as that obtained before, showing A and V waves of equal amplitude. In the second, a patient with auricular fibrillation (Fig. 8) the V wave became much higher after valvotomy and the slight drop in pressure after the C wave, which was present before valvotomy, disappeared. In the third patient (Fig. 9) the changes were of special interest. The mean left atrial pressure rose after valvotomy from 24 to 26 mm. Hg. This rise was attributable chiefly to a rise in the height of the V wave, from 32 to 37 mm. Hg, whereas the peak of the A wave *dropped* from 23 to 19 mm. Hg and the C wave from 28 to 26. Further analysis of these curves showed that the mean systolic pressure rose, while the mean diastolic pressure dropped slightly. The mean diastolic gradient between atrium and ventricle dropped from 20 to 14 mm. Hg, chiefly because of a rise in the diastolic pressure in the ventricle. The pressure tracings, therefore, confirmed the surgeon's opinion that the mitral stenosis was relieved but that mitral insufficiency was produced. It is of interest that all three of these patients were worse after operation than before.

Summary of Left Atrial Pressure Findings. The pressure pulses in mitral stenosis were no different from the normals except that the pressure level was higher. With auricular fibrillation the A wave was absent and the C and V waves formed a plateau. The cases of mitral insufficiency were too few to allow final conclusions but they tended to show an increase in the height of the V wave and more sustained pressure between the C and V waves, in both sinus rhythm and auricular fibrillation. The height of the left atrial pulse pressure was of no diagnostic importance. None of the previously

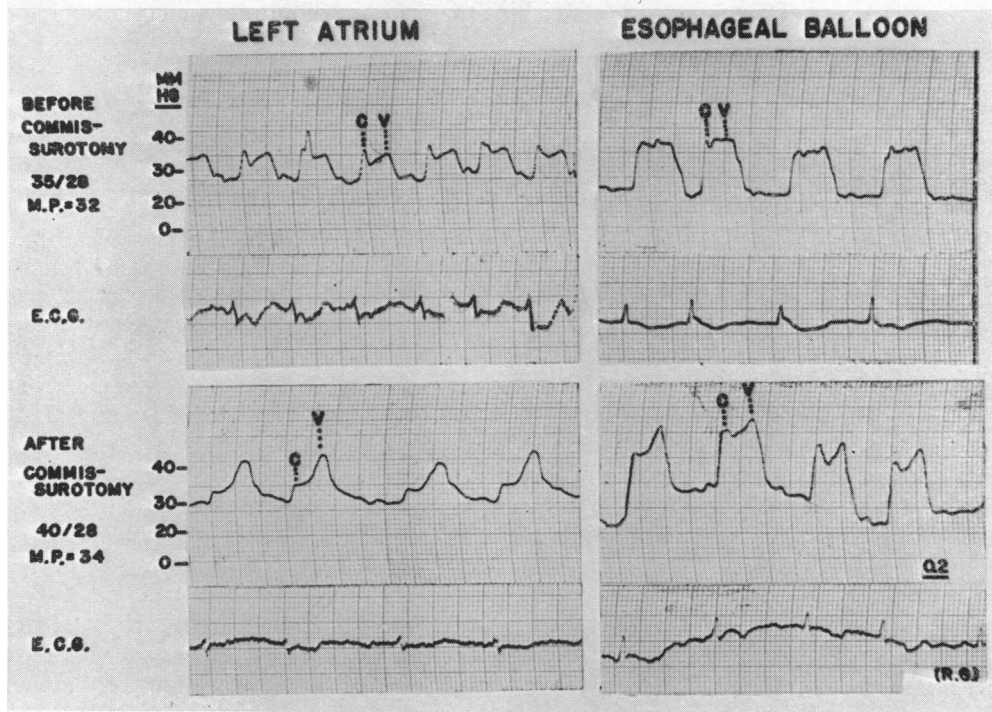


FIG. 8.—Tracings taken before and after valvotomy in a patient who developed a strong regurgitant jet as the result of surgery.

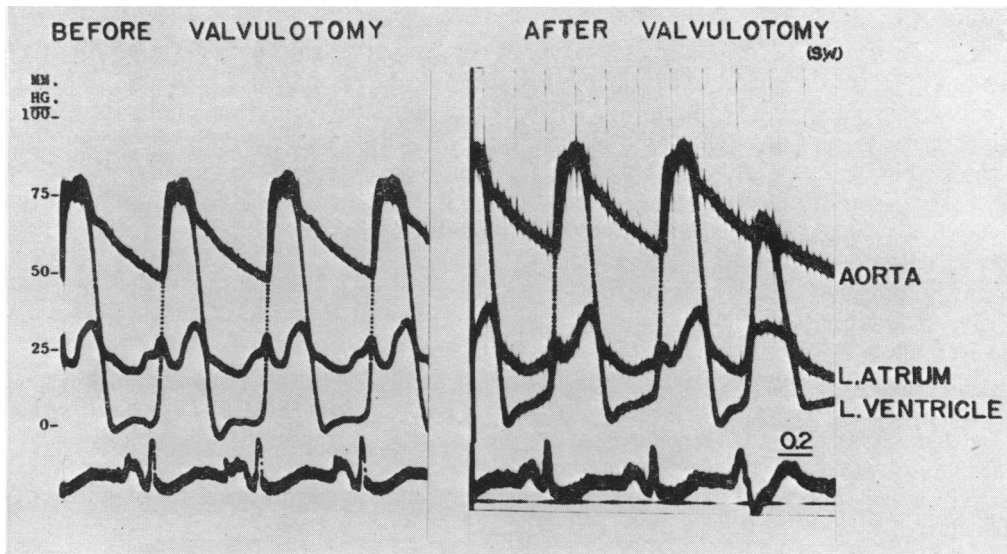


FIG. 9.—Simultaneous left atrial, left ventricular, and aortic pressure pulses before and after valvotomy in another patient who developed mitral insufficiency after surgery. Described in text. (Paper speed = 50 mm. per second.)

proposed criteria were of much help in establishing the presence of mitral insufficiency, either when alone or in combination with mitral stenosis.

"PULMONARY CAPILLARY" PRESSURES

These were the most difficult both to obtain and to interpret. "P.C." pressures could be obtained in only 19 of 27 patients who had cardiac catheterization. In three of these, the curves were non-phasic, constituting either mean pressures or mean pressures with superimposed artefacts. Difficulties in obtaining satisfactory "P.C." curves have been encountered by others (Venner and Holling, 1953). A failure to obtain "P.C." curves in eight patients was attributed to a variety of causes; most often the catheter formed a loop in the right auricle or main pulmonary artery when attempts were made to wedge the tip. In at least two patients the catheter was properly wedged but the tracings were pulmonary artery tracings.

Thus, difficulties in obtaining "P.C." pressures may be divided into two categories: (1) a group that could probably be eliminated by improvements in technique (Wood, 1953); and (2) a group in which for some unknown reason, it is impossible to obtain "P.C." pressures. We attempted to determine whether there was any common denominator among the latter. We found no correlation with the height of the pulmonary artery pressure or with the clinical picture. However, of the 15 patients with auricular fibrillation who were catheterized, the "P.C." pressures were unsatisfactory in nine, whereas in the 12 patients with sinus rhythm, only two were unsatisfactory, a much lower percentage.

Even when "P.C." pressures were obtained, they contained numerous artefacts, probably mainly due to movement of the catheter within the beating heart. These artefacts made it difficult, in many instances, to define the onset of the various waves, so that for purposes of timing hæmodynamic events the "P.C." pressures were the least satisfactory.

Normal "P.C." Pressures. The normal human "P.C." pressure pulse may show considerable variation from case to case, but consists, in its ideal form of A, C, and V waves differing in no essential details from the left atrial pressure pulse, with the exception of a slight delay in transmission. Because of artefacts of catheter movement, and damping within the catheter manometer-recording system, the C wave often cannot be identified. The relative heights of the A and V waves may vary.

"P.C." Pressure in Mitral Valve Disease. When one takes into consideration that they were obtained at different times and under different conditions, the resemblance between "P.C." and left atrial curves was good (Fig. 1, 4, and 6). There were, however, many exceptions (Fig. 3) so that, in a given case, the left atrial curves could not be predicted from the "P.C." with any assurance. In 17 cases where both "P.C." and left atrial pressures were obtained, they resembled each other in 10. A comparison of mean pressures in the "P.C." and left atrium (Table I) showed fair correlation, with no systematic deviations related to the cardiac rhythm or the nature of the valvular lesion.

As in the normal "P.C." pressure pulse, the C waves were often impossible to identify when sinus rhythm was present. However, in auricular fibrillation the pressure rise with the onset of systole was often abrupt and clear (Fig. 4). When the V wave was prominent in the left atrial tracing, this was often reflected in the "P.C." although in the latter it was often split. As compared with corresponding waves in the left atrial tracings (Table II), our "P.C." curves showed a fairly constant delay of 0.05 sec. This is essentially the same figure reported by Connolly *et al.* (1953) (0.05 sec.) and by Wolter *et al.* (1953) (0.06 sec.).

In no instance did we find the "P.C." tracing of any value in the preoperative diagnosis of mitral insufficiency.

ESOPHAGEAL BALLOON PRESSURE PULSES

From the technical standpoint satisfactory curves were obtained in every instance. The procedure, however, was time consuming and proved to be distressing to the patient. This is reflected

TABLE I
DIRECT LEFT ATRIAL, AND "P.C." PRESSURES IN 30 PATIENTS OPERATED UPON FOR MITRAL STENOSIS

Patient	Age	Sex	Surgical diagnosis	Rhythm	Left atrial pressures (mm. Hg)				"P.C." pressures (mm. Hg)			
					Max.	Min.	Mean	Pulse pressure	Max.	Min.	Mean	Pulse pressure
J.S.	33	F.	M.S.	S.R.	60	38	43	22	45	15	34	30
N.S.	39	M.	M.S.	S.R.	40	30	37	10	40	34	37	6
A.B.	50	F.	M.S.	S.R.	47	25	28	22	43	20	31	23
S.P.	31	M.	M.S.	S.R.	33	24	27	9	30	12	19	18
R.R.	42	F.	M.S.	S.R.	33	19	23	14	27	12	21	15
E.D.	37	F.	M.S.	S.R.	13	3	8	10	N.C.			
E.K.	29	F.	M.S.	S.R.	42	23	33	9	30	16	22	14
P.B.	24	F.	M.S.	S.R.	35	15	28	20	30	15	24	15
L.R.	32	F.	M.S.	S.R.	33	16	26	17	43	16	30	27
G.H.	36	F.	M.S.	S.R.	39	20	25	19	N.O.			
I.M.	34	F.	M.S.	S.R.	36	21	26	15	37	14	26	23
El. C.	39	F.	M.S.	A.F.	45	22	30	23	40	34	38	6
E.M.	32	F.	M.S.	A.F.	27	18	21	9			30	
F.G.	36	F.	M.S.	A.F.	44	32	35	12	N.O.			
J. di G.	49	F.	M.S.	A.F.	40	25	32	15	N.O.			
E.H.	37	F.	M.S.	A.F.	32	18	25	14	N.O.			
R.L.	33	F.	M.S.	A.F.	20	9	15	11			28	
G.B.	32	F.	M.S.	A.F.	30	22	27	8	24	15	22	9
S.Pa.	37	F.	M.S.	A.F.	38	19	28	19	N.O.			
A.K.	37	F.	M.S.	A.F.	16	6	11	10	N.C.			
E.S.	31	F.	M.S.	A.F.	30	15	24	15	25	13	19	12
M.G.	42	F.	M.S.	A.F.	17	9	13	8	24	11	16	13
J.M.	33	M.	M.S. & M.I.	S.R.	40	25	32	15	N.O.			
S.W.	45	M.	M.S. & M.I.	S.R. & A.F.	35	17	26	18	N.O.			
F.C.	30	M.	M.S. & M.I.	A.F.	42	30	38	12	28	18	26	10
H.C.	46	M.	M.S. & M.I.	A.F.			18		N.O.			
R.G.	41	F.	M.S. & M.I.	A.F.	35	28	32	7			18	
E.C.	39	M.	M.S. & M.I.	A.F.				8	33	17	31	16
W.B.	28	M.	M.I.	S.R.	30	17	23	13	40	25	35	15
C.H.	42	F.	M.I.	A.F.	55	35	40	20	N.C.			

M.S. = Mitral stenosis
M.I. = Mitral insufficiency

S.R. = Sinus rhythm
A.F. = Auricular fibrillation

N.O. = Not obtained
N.C. = Not catheterized

TABLE II
TIME BETWEEN QII AND ONSET OF C WAVE IN PRESSURE PULSES*

Patient	Diagnosis	Rhythm	QII to onset of C wave (seconds)		
			Left atrium	"P.C."	Æsoph. balloon
G.B.	M.S.	A.F.	0.05	0.10	0.04
I.M.	M.S.	S.R.	0.05	0.10	0.06
E.S.	M.S.	A.F.	0.05	0.10	0.05

* No correction made for time of passage of pulse wave through catheter or polythene tubing.

in the fact that the heart rate was much more rapid during the œsophageal balloon procedure than the cardiac catheterization and with rare exceptions it was also more rapid than during surgery. As indicated previously, one of the drawbacks of the method is the inability to obtain absolute pressure values. Artefacts were generally less troublesome than in the "P.C." tracings, because of less motion of the polyethylene tubing than the cardiac catheter.

Normal œsophageal balloon tracings have been described by Lasser and colleagues as being reflections of the left atrial pressure pulse. As in the other curves with which we are dealing, we have found considerable variation even in normal patients. A, C, and V waves may be identified, as in Fig. 10, although they are usually not as well defined as in this figure and may be split.

As compared with the normal, œsophageal balloon tracings in mitral valve disease showed a higher amplitude but little qualitative difference. The resemblance to direct left atrial tracings was good (Fig. 2, 6, 7), although exceptions also occurred here. Preoperative œsophageal balloon tracings gave a better indication than "P.C." curves of the contour of the left atrial pulse subsequently obtained at operation.

œSophageal balloon and left atrial tracings were obtained in all 30 patients in the study. In one patient, the rhythm changed from auricular fibrillation at the time the balloon tracing was taken to sinus rhythm at operation, so the curves could not be compared. Of the remaining 29, in 20 the balloon tracing resembled the left atrial tracing. On the other hand, in 20 cases in which both "P.C." and œsophageal balloon curves were available, they resembled each other in only six. The correspondence between balloon and atrial pressure pulses was more pronounced in auricular fibrillation, probably because the curves are less complex when that rhythm is present.

When the V wave was prominent in the direct left atrial tracing, this prominence was often, but not always, reflected in the œsophageal balloon tracing (Fig. 6 and 7). However, we have been unable to confirm the presence of characteristic œsophageal balloon tracings in mitral stenosis or mitral insufficiency. It is true that a prominent late systolic wave (V wave) and a tendency for the curve not to fall to the base line after the C wave are found more often in mitral insufficiency than in mitral stenosis. We obtained the best example of such a tracing (Fig. 10) in a patient who was operated upon elsewhere.* This patient was found at operation to have marked mitral insufficiency. In another case, previously mentioned, in whom very mild insufficiency was greatly aggravated by

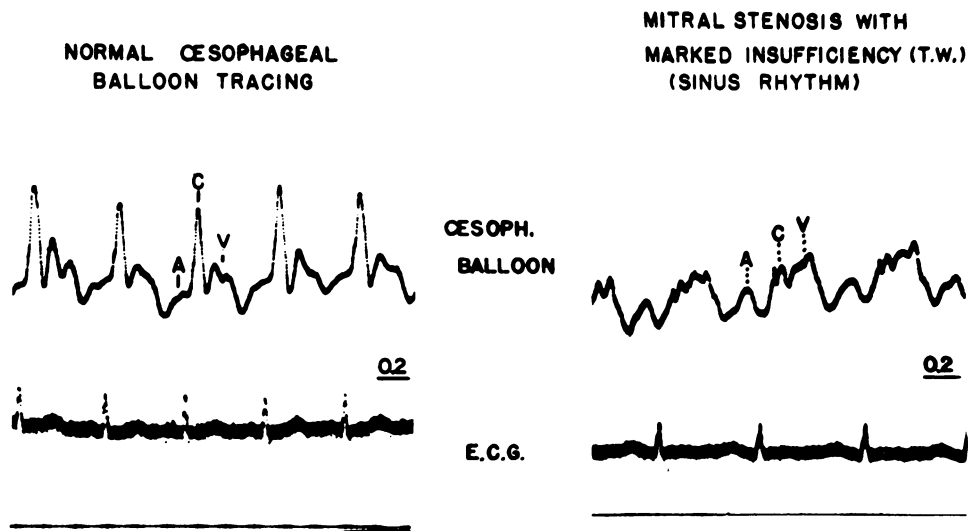


FIG. 10.—(A) Normal œsophageal balloon pulse tracing. (B) Tracing in a patient with proven mitral insufficiency and no stenosis. (Paper speed = 50 mm. per second.)

* We are indebted to Dr. Jere Lord, of the University Hospital, New York, for permission to study this case.

valvotomy, the post-operative œsophageal balloon tracing reflected to some extent the increased height of the V wave (Fig. 8). Unfortunately, the features mentioned above are not pathognomonic for mitral insufficiency, as they also occur in pure mitral stenosis, and are absent in an occasional patient with mitral insufficiency. In a given patient, therefore, the œsophageal balloon appears to have little or no value in the preoperative diagnosis of mitral insufficiency.

TABLE III
COMPARISON OF TIME BETWEEN ELECTRICAL AND MECHANICAL EVENTS IN LEFT ATRIAL AND
ÆSOPHAGEAL BALLOON TRACINGS*

	Left atrium		Æsophageal balloon	
	No. of cases	Average time (in seconds)	No. of cases	Average time in (seconds)
P to onset of A ..	9	0.06	9	0.07
P to peak of A ..	9	0.14	9	0.15
Q to onset of C ..	15	0.05	15	0.05
Q to peak of C ..	15	0.10	15	0.10
Q to onset of V ..	13	0.20	15	0.17
Q to peak of V ..	13	0.33	15	0.23

* No correction made for time of passage of pulse wave through catheter or polythene tubing.

In a group of cases in which accurate measurement was possible (Tables II and III) the time of inscription of the A and C waves relative to the electrocardiogram was the same in the œsophageal balloon as in the direct left atrial tracings. The V wave occurred slightly earlier in the former, possibly because of the more rapid heart rate.

SUMMARY

Direct left atrial, "pulmonary capillary", and œsophageal balloon pressure pulses were recorded in a series of 30 patients operated upon for mitral stenosis. The purpose of the study was to determine how closely the "P.C." and œsophageal balloon tracings reflected those obtained directly from the atrium, and to estimate their value in the diagnosis of mitral insufficiency.

Of 27 patients who had pre-operative cardiac catheterization, "P.C." curves could be obtained in only 19. In all 30 patients satisfactory œsophageal balloon curves were obtained preoperatively and good left atrial tracings were recorded at operation.

With some exceptions, there was good correspondence among the three types of pressure curves recorded in a given case. However, there were many artefacts in both the "P.C." and œsophageal balloon tracings, which impaired their value.

In cases with pure mitral stenosis and sinus rhythm, the tracings showed no qualitative difference from the normal, but the pressure level was much higher. Auricular fibrillation gave rise to a plateau type of tracing beginning with the C wave and ending with the V wave.

Five of the 30 patients proved at operation to have mitral incompetence. Three developed this lesion after the valve was split.

Mitral insufficiency, either alone or in combination with mitral stenosis, tended to augment the V wave and prevent much of the pressure fall after the C wave. Changes of this character were unimpressive in the presence of auricular fibrillation, did not occur in every case of mitral insufficiency in sinus rhythm, and occasionally were present in what appeared to be pure mitral stenosis.

It was concluded that direct left atrial, "pulmonary capillary", and œsophageal balloon pressure pulses could not be relied upon to diagnose mitral insufficiency when mitral stenosis was also present.

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